THERMOELECTRIC BONDING STUDY

QUARTERLY PROGRESS REPORT

COVERING THE PERIOD FROM
1 April Through 30 June 1966

August 1966

Work performed under
NASA Contract NAS5-3973

Prepared for
National Aeronautics and Space Administration

HITTMAN ASSOCIATES, INC.
BALTIMORE, MARYLAND

LEGAL NOTICE

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FOREWORD

This report covers the work accomplished during the period 1 April through 30 June 1966 under NASA Contract NAS5-3973, Thermoelectric Bonding Study. Mr. Joseph Epstein is Technical Officer for NASA-GSFC.

I. INTRODUCTION

Hittman Associates, Inc., under Contract NAS5-3973, has been continuing the study of bonding of lead telluride thermoelectric elements to metal shoes. During earlier phases of this program it was found that two principal mechanisms contribute to the failure of bonded lead telluride thermoelements.

(1) Diffusion of material from the braze or shoe into the lead telluride causing poisoning and attendant decrease in power output.

(2) Cracking of the lead telluride caused by stresses resulting from thermal expansion mismatch during bonding.

A comparison of several alternate materials led to the selection of SnTe-1^{W}/oTi as a braze and iron as an electrical contact material for further detailed study. Long term life tests and detailed post-test analysis showed that, under the test conditions, performance of n-PbTe is unchanged while the output of p-PbTe thermoelements declines. The observed decline apparently results from an increase in electrical resistance within the element in the vicinity of the hot shoe bond. During the current reporting period testing of thermoelectric elements has continued and further studies of the bond zone have improved our understanding of the mechanisms of degradation.

Earlier in the program the effect of molybdenum and tungsten in strengthening p-PbTe was observed. This study has been continued and more quantitative data on the effects of these additives have been obtained.

Progress in these areas are described in detail in succeeding chapters of this report.

II. LIFE TESTING OF BONDED LEAD TELLURIDE

Life tests of n-PbTe and p-PbTe have continued during this quarter. The equipment and test procedures have been described in detail in previous reports (Reference 1, for example). In order to obtain maximum information on the effects of test conditions on the factors affecting bond integrity, individual elements rather than couples or modules have been tested during this program.

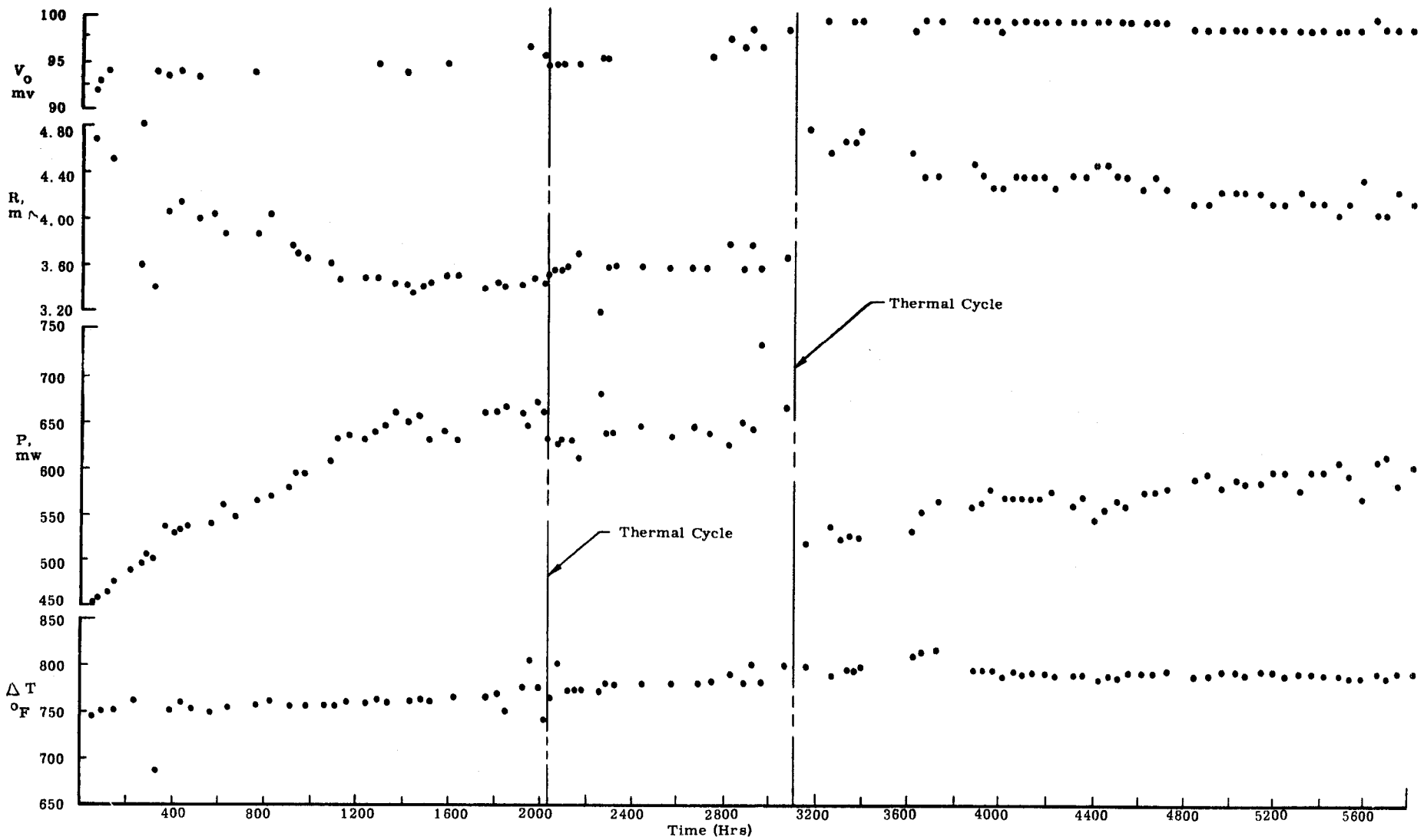
A. Tests of n-PbTe Thermoelectric Elements

During this quarter a group of n-PbTe elements were removed from test after approximately 6,000 hours of operation. These elements included three Hittman Associates produced TEG-2N thermoelements bonded to iron shoes, one 3M Company produced TEGS-2N element bonded at the hot end only, and two unbonded controls, one produced at Hittman Associates and the other purchased from 3M.

Figures 1 through 3 show the performance of the bonded test elements. Over the first 2,000 hours power increased steadily due to a continual decline in resistance. At this point, a utility failure caused two thermal cycles. Immediate increases in resistance and declines in power were observed. These were largely recovered within a few hundred hours. A heater failure caused a thermal cycle and temporary shutdown of the system after 3,100 hours. During attempts to remove the failed heater, which was stuck firmly in the heater block, the elements were unintentionally stressed. Upon restart this was manifested as a sharp rise in resistivity and accompanying decline in power. During the last 3,000 hours of testing the power output of elements 186 and 189 (Figures 1 and 2) slowly increased to approximately the level measured immediately prior to the failure. The output of element 197 (Figure 3) remained substantially below earlier levels.

Upon removal from the life tester all the elements appeared sound. The iron hot shoes generally displayed an oxide layer although the PbTe showed less discoloration. Figure 4 shows the appearance of a typical element. The cold shoe of element 197 separated during handling. Incipient failure of this bond apparently had caused the unrecovered power decline discussed above. The hot shoes of the two contact bond elements had bonded to the elements during the extended time at temperature. The resistance of these bonds were measured along with other pertinent resistances and Seebeck coefficients and are compared to pre-test values in Table 1. Changes in bond resistance, resistivity and Seebeck coefficient were small in the four bonded elements and were probably within the experimental accuracy of the test equipment. The electrical resistivity of the two unbonded thermoelectric elements showed significant changes, declining 13 and 18 percent in the two samples. The cause of this is not apparent. As was stated previously, the hot shoes adhered to these elements during the test. Contact resistances, which were 570 and 420 $\mu\Omega$, were high when compared to the 40 to 80 $\mu\Omega$ measured on the braze bonded samples after testing.

The elements were mounted, polished and examined metallographically. This examination showed that extensive oxidation had occurred at the hot junction bond of all the elements. This was manifested in two ways - a heavy layer of



$T_H = 940^{\circ}F$

Figure 1. Performance of n-PbTe Element Number 186 During 5900 Hour Life Test

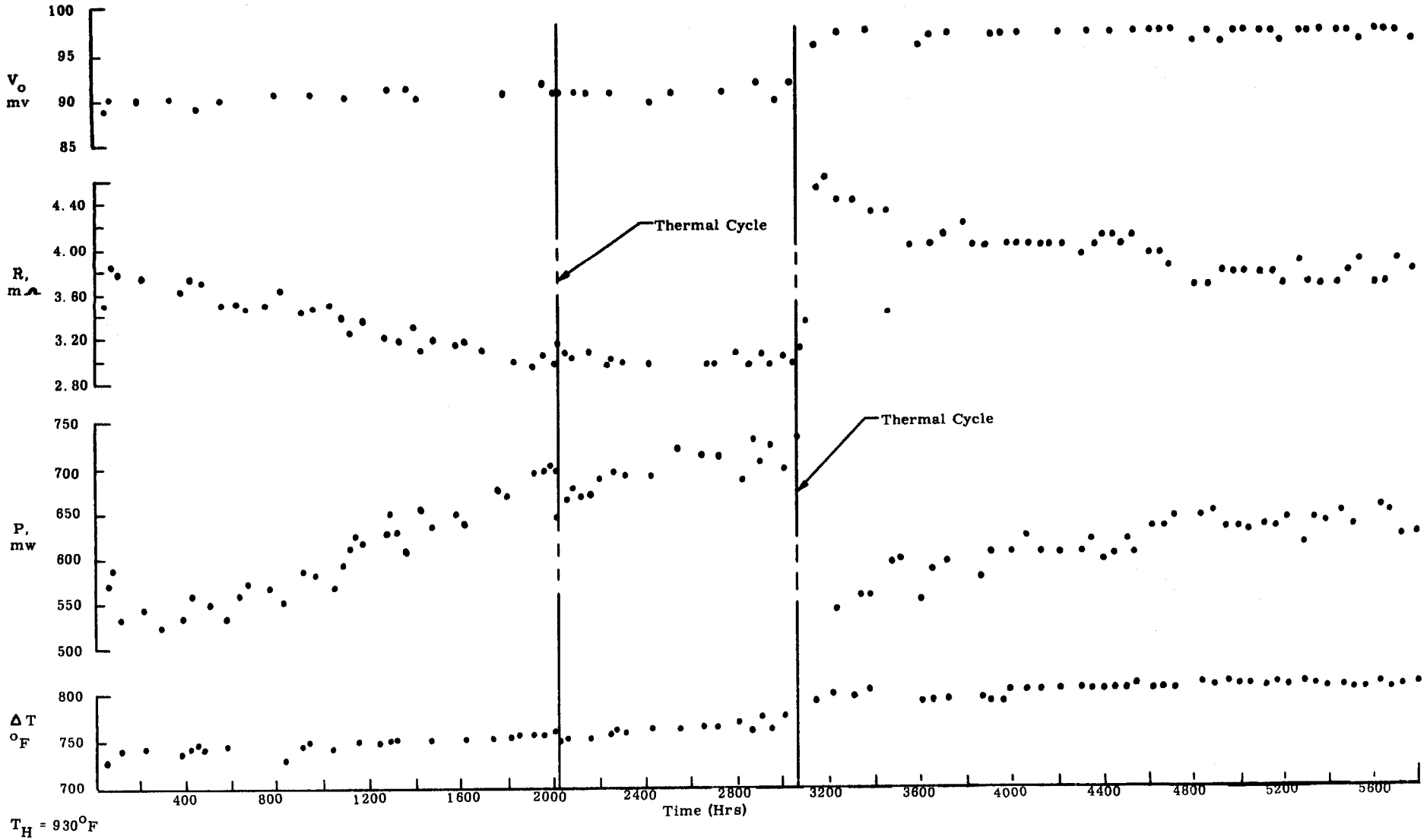
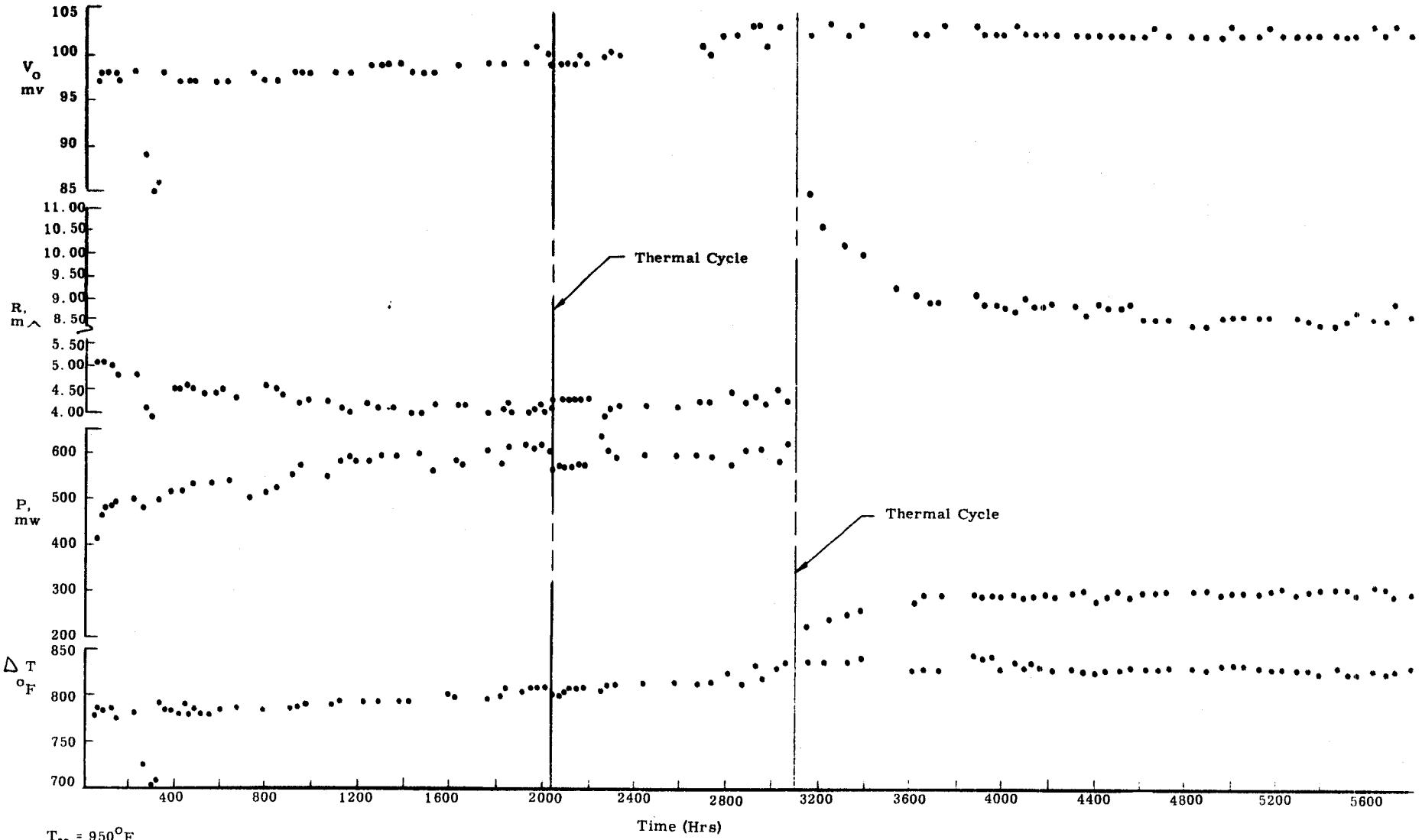
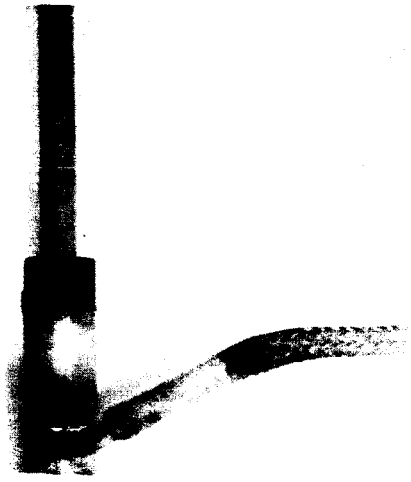


Figure 2. Performance of n-PbTe Element Number 189 During 5900 Hour Life Test



$T_H = 950^oF$

Figure 3. Performance of n-PbTe Element Number 197 During 5900 Hour Life Test



189A
n-PbTe

Figure 4 Appearance of Element No 189 After 5900 Hour Life Test

TABLE I

Properties of n-PbTe Thermoelectric Elements after 5900 Hour Life Test

Sample No.	Composition	Bond Resistance, μΩ Before Test Hot	Bond Resistance, μΩ Before Test Cold	Bond Resistance, μΩ After Test Hot	Bond Resistance, μΩ After Test Cold	Room Temp Resistivity, μΩ-in As Pressed	Room Temp Resistivity, μΩ-in As Bonded	Room Temp Resistivity, μΩ-in After Life Test	Seebeck Coefficient Data: As Pressed Temp, °C	S, μV/°C	% deviation from 3M Values	Seebeck Coefficient Data: As Bonded Temp, °C	S, μV/°C	% deviation from 3M Values	Seebeck Coefficient Data: After Life Test Temp, °C	S, μV/°C	% deviation from 3M Values
202	TEG-2N n-PbTe	Contact	Bond	570	Contact	190	---	155	105	157	-14.2				66	174	+ 4.2
									165	186	- 9.7				98	192	+ 6.7
197	TEG-2N n-PbTe	70	63	40	Separated	164	171	179	104	165	- 9.3	79	155	- 9.9	76	165	- 3.5
									160	189	- 7.4	138	180	- 8.2	108	185	+ 0.5
3M-3	TEGS-2N n-PbTe	Contact	Bond	420	Contact	192	---	167	97	162	- 9.5				63	164	- 1.2
									157	193	- 4.9				96	177	- 1.2
186	TEG-2N n-PbTe	48	0	80	0	182	170	169	102	164	- 9.4	89	154	-12.5	62	141	-14.5
									162	188	- 8.3	138	176	-13.3	98	165	- 8.3
3M-2	TEGS-2N n-PbTe	40	Contact	50	Contact	193	174	181	96	164	- 8.4	92	154	-13.0	60	126	-23.7
									152	184	- 8.5	139	173	-11.7	88	154	-12.5
189	TEG-2N n-PbTe	40	5	50	50	169	171	185	95	176	- 1.7	93	156	-12.4	62	152	- 7.9
									149	195	- 2.5	143	176	-11.1	95	165	- 7.8

oxide at the iron-braze interface and an oxide phase distributed throughout the braze. Figure 5a, a photomicrograph of element 3M-2 shows both these effects and Figure 5b, which shows bond zone of element 197, displays only the oxide dispersion within the braze. The diffusion bonds formed during test in the initially unbonded thermoelements were also oxidized as can be seen in Figure 6. As was noted above, despite the observed oxidation, bond resistance was unaffected in the braze bonded samples.

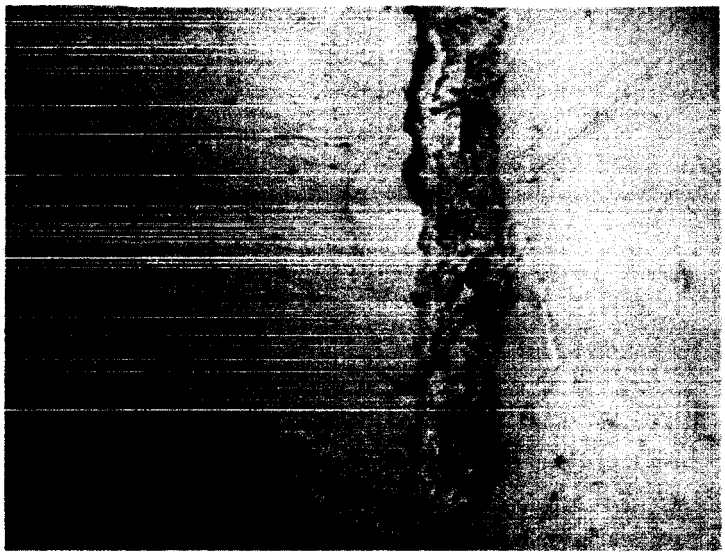
Several of the above thermoelectric elements will be sent to GSFC for electron microprobe analysis.

An additional test of six n-PbTe elements was started during this quarter, but extensive property data have not yet been obtained.

B. Tests of p-PbTe Thermoelectric Elements

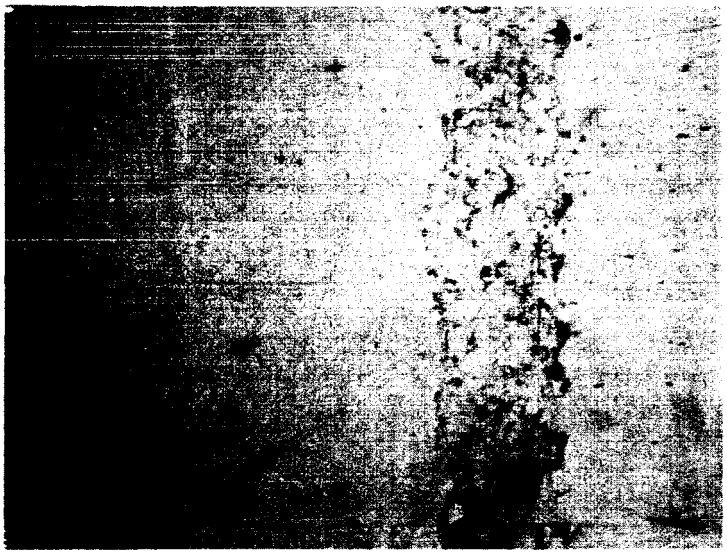
Two long-term life tests of p-PbTe elements have continued in operation and have passed 3,600 and 2,700 hours respectively. Both TEG-2P elements and similar samples containing an addition of one percent by weight of molybdenum are included among the twelve individual test elements. In almost every one of these elements an initial rapid decline in power output was observed, followed by a steady drop at a lower rate, 5-10% per 1,000 hours. The performance curves for the 3,600 hour test are shown in Figures 7-12, while Figures 13-18 represent the performance of the 2,700 hour test. Both tests are continuing.

Electron microprobe studies are being performed at GSFC on several samples of p-PbTe that had been life tested for 500 and 1,745 hours (Reference 1). While full quantitative results are not yet available it is clear that diffusion of tin into the PbTe occurs in much the same manner and at rates similar to those observed in n-PbTe and reported earlier. Quantative data will be reported when available.



a) Element #3M-2
Mount #1420

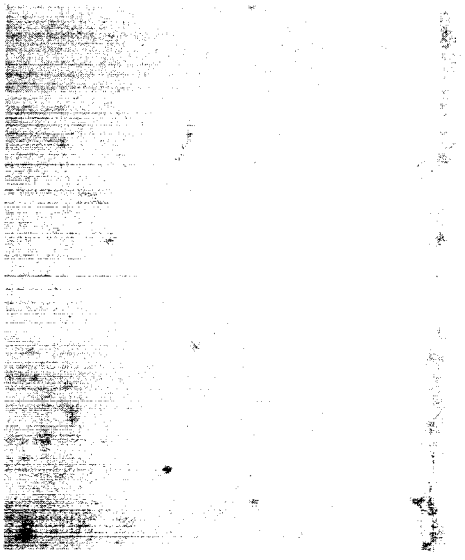
260 X



b) Element #197
Mount #1417

260 X

Figure 5 Appearance of Bond Zone in Brazed n-PbTe Elements After 5900 Hour Life Test



Element #202 260 X

Mount #1421

Figure 6 Appearance of Diffusion Bonded Interface Between Iron and n-PbTe Formed During 5900 Hour Life Test

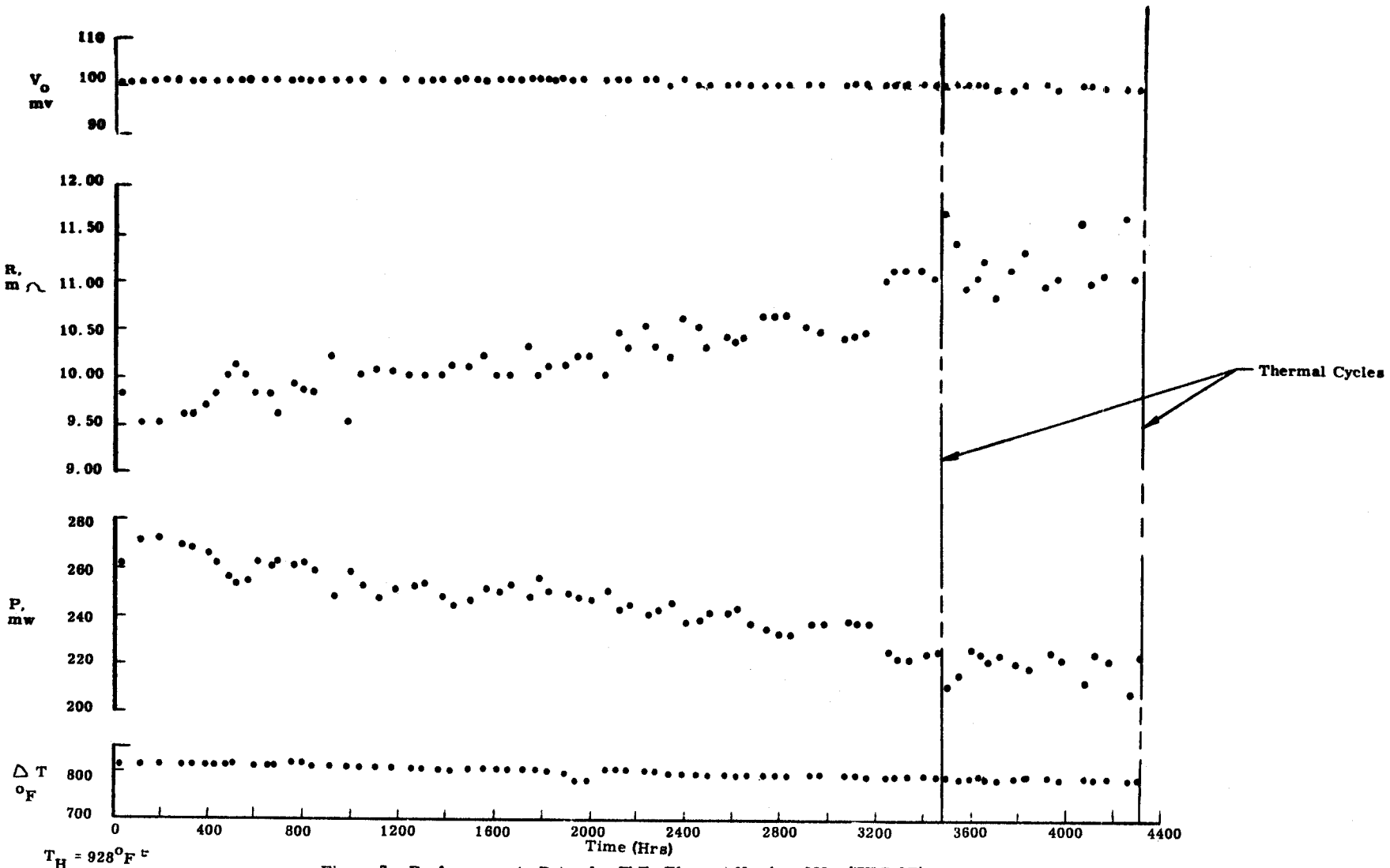


Figure 7. Performance to Date of p-PbTe Element Number 339 (TEG-2P)

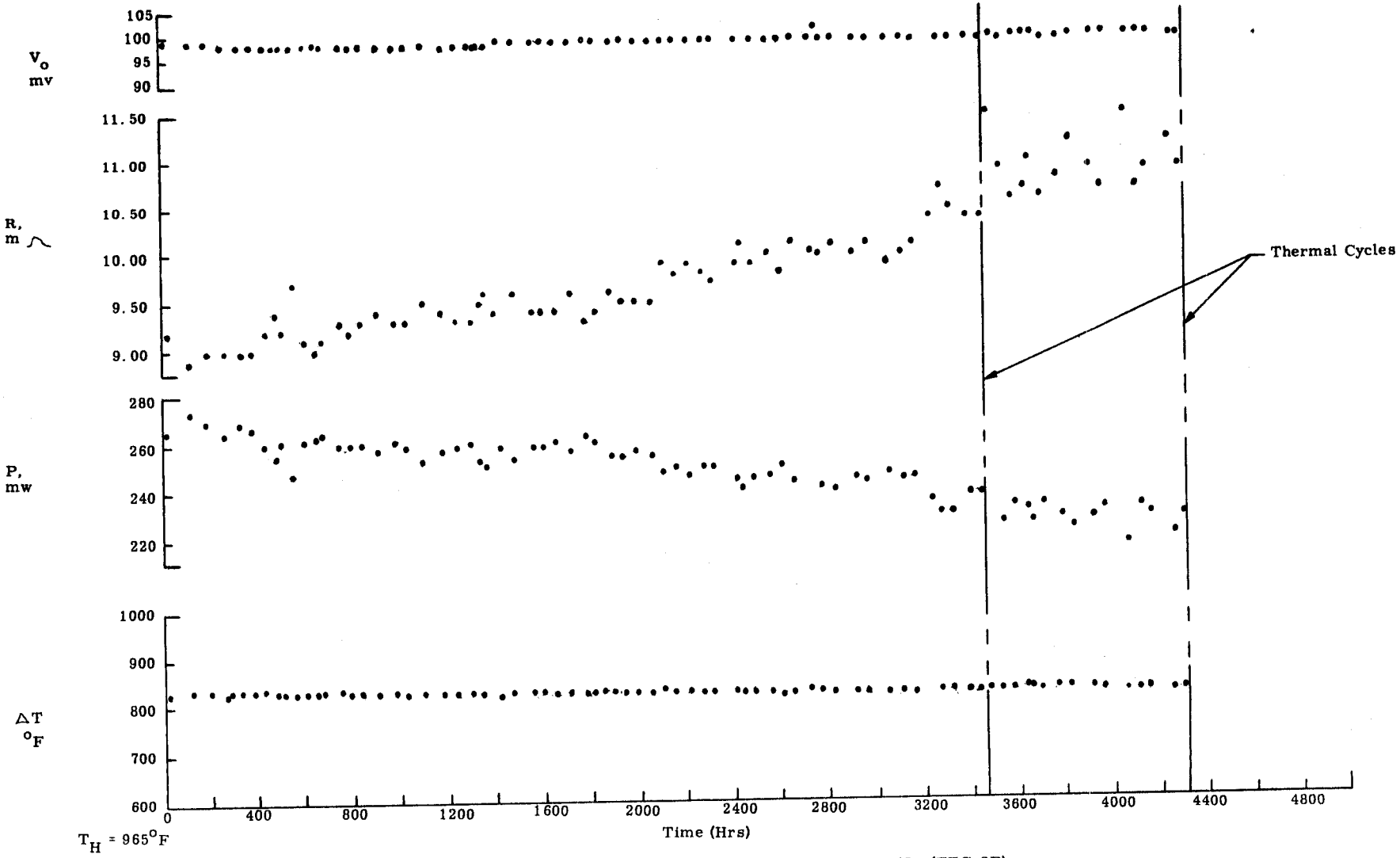


Figure 8. Performance to Date of p-PbTe Element Number 348 (TEG-2P)

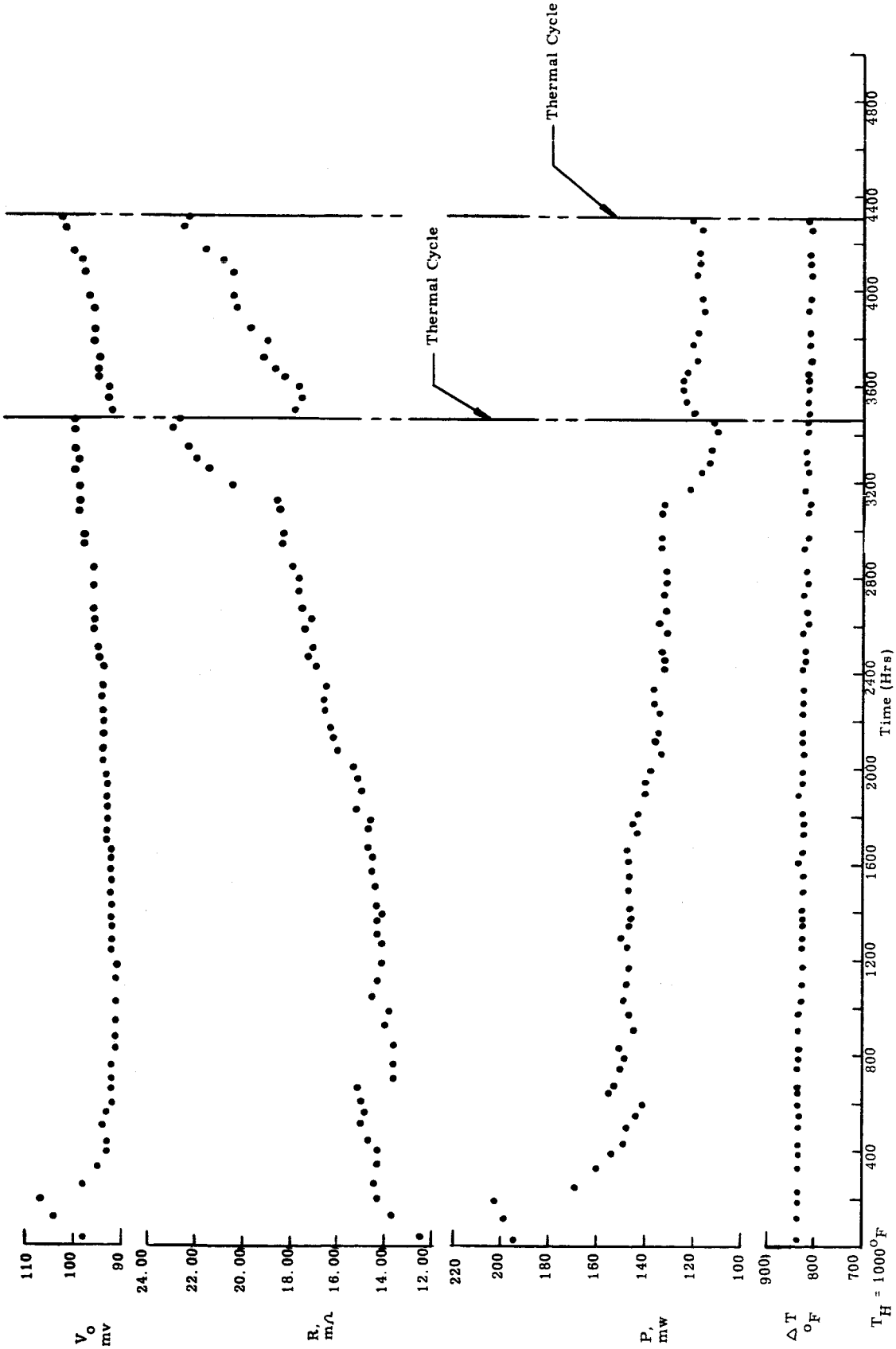


Figure 9. Performance to Date of p-PbTe Element Number 249 (TEG-2P)

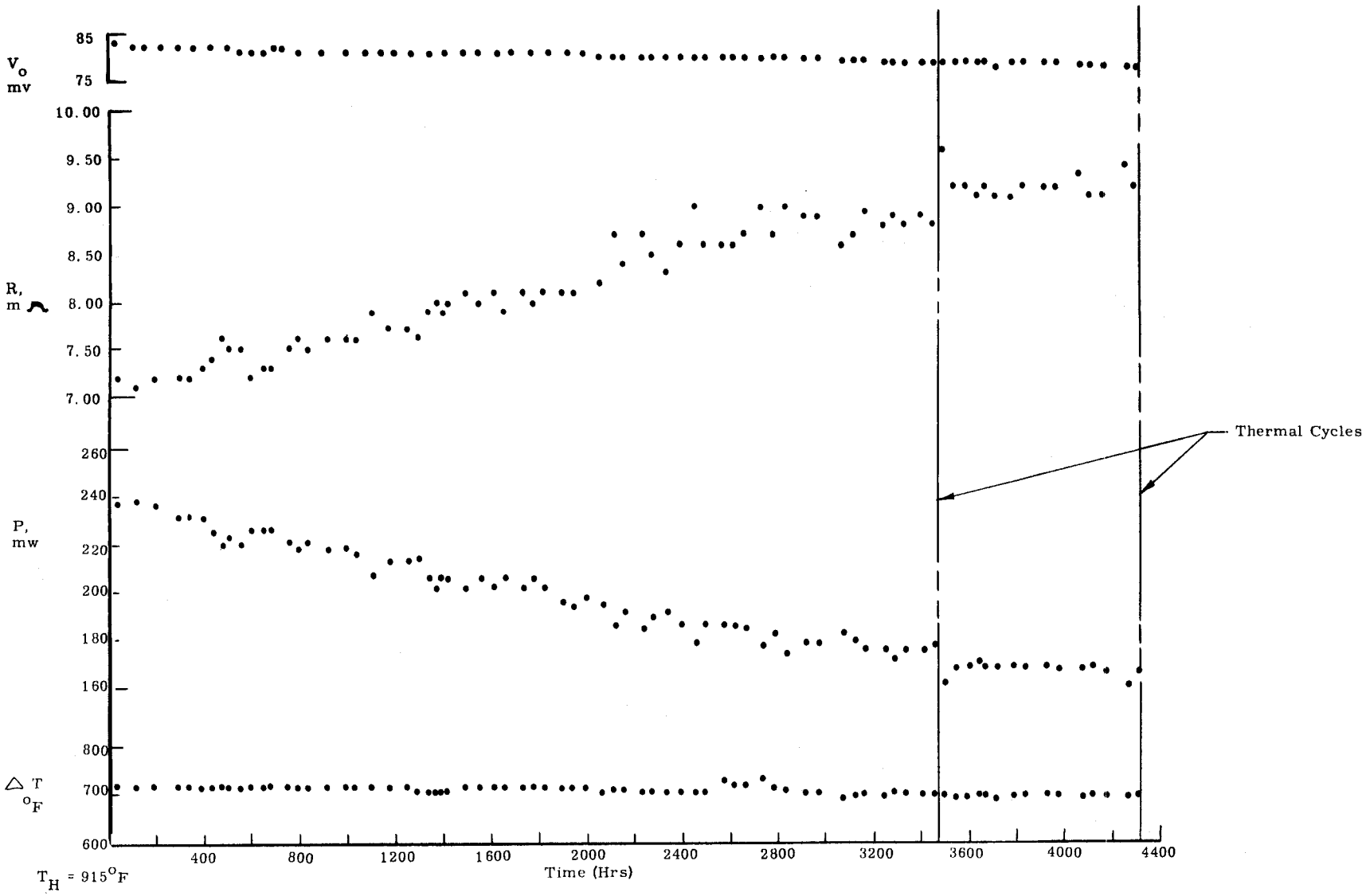


Figure 10. Performance to Date of p-PbTe Element Number 327 (TEG-2P + 1% Mo Fibers)

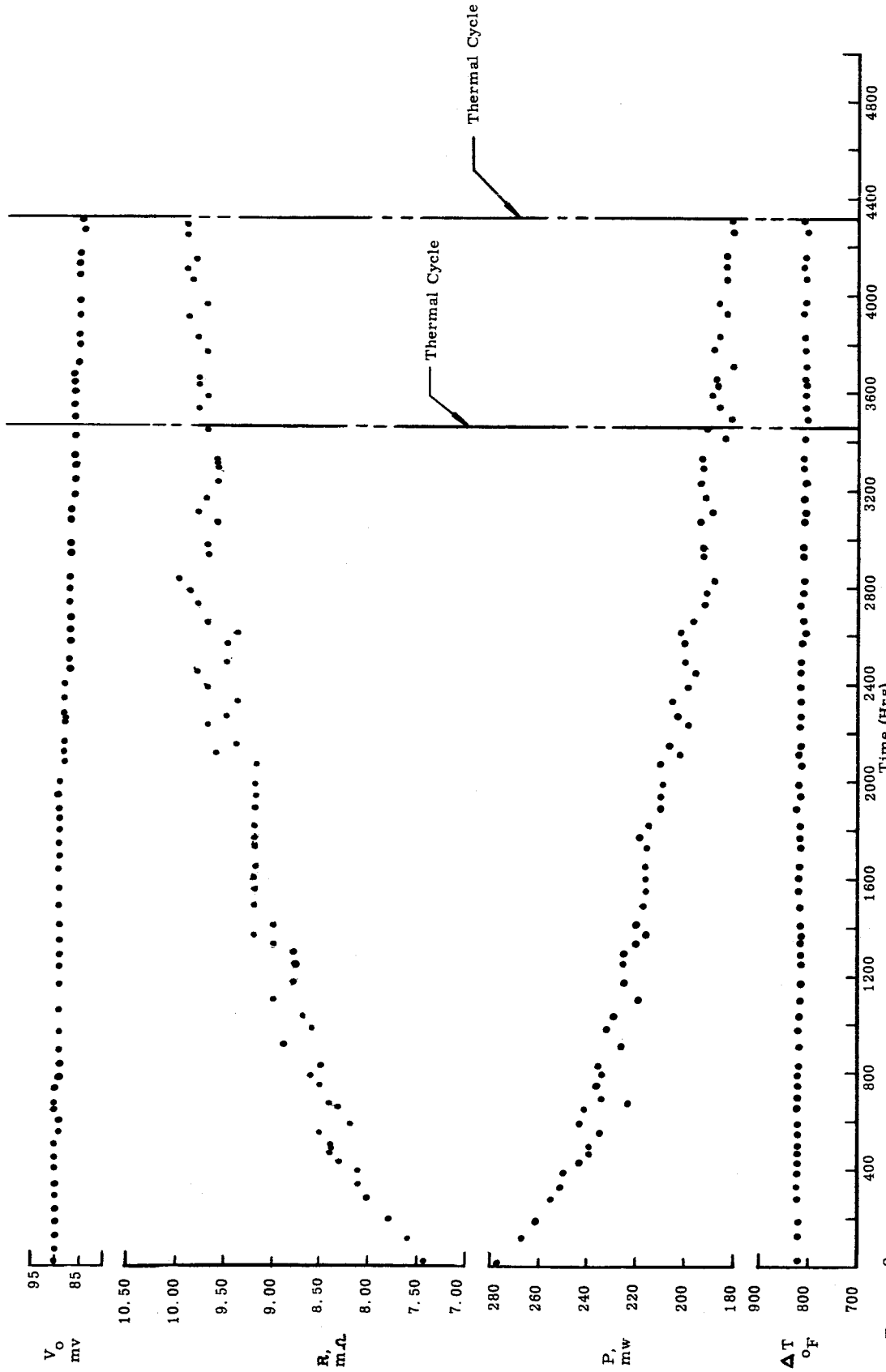


Figure 11. Performance to Date of p-PbTe Element Number 325 (TEG-2P + 1% Mo Fibers)

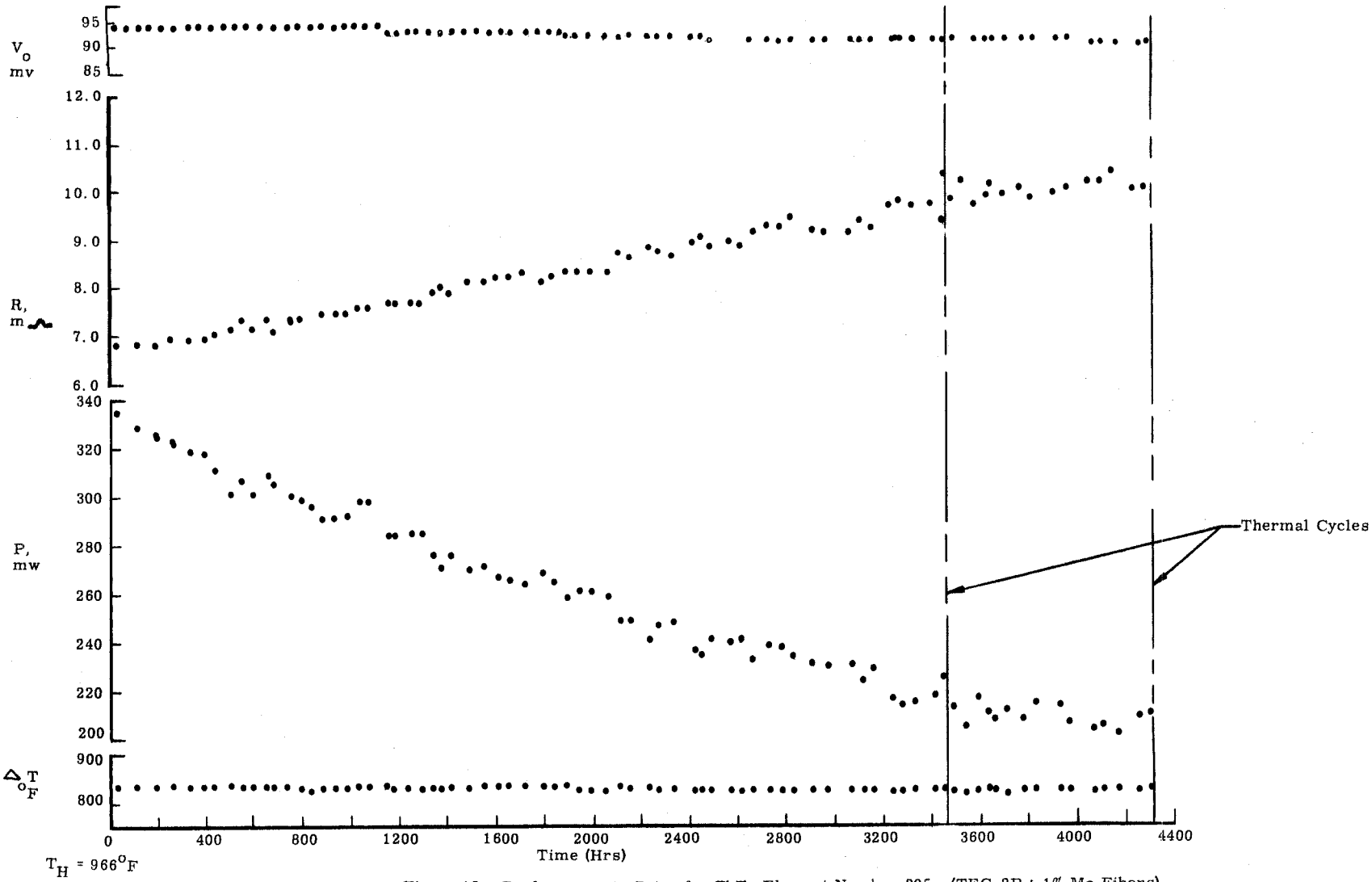


Figure 12. Performance to Date of p-PbTe Element Number 305 (TEG-2P + 1% Mo Fibers)

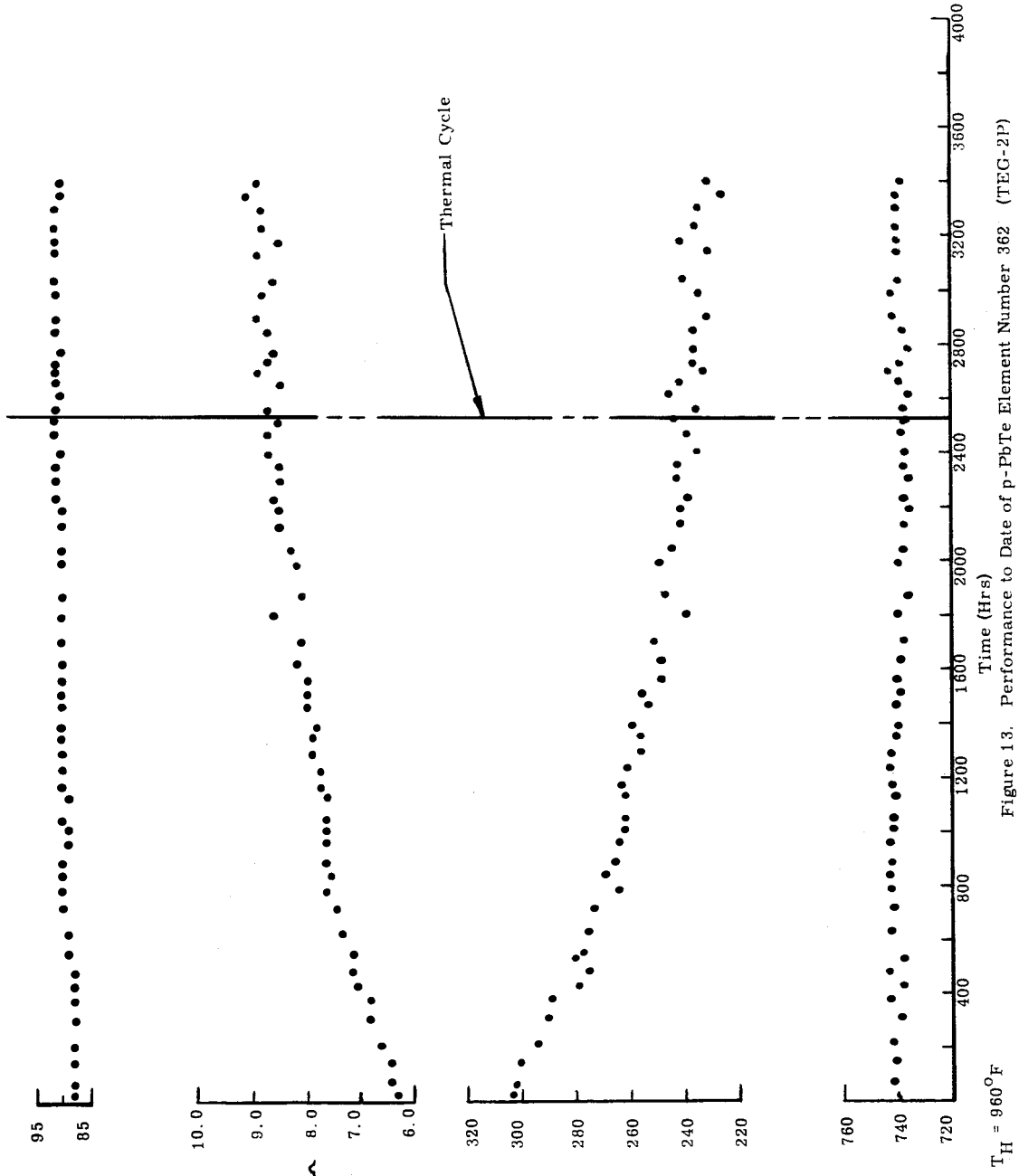


Figure 13. Performance to Date of p-PbTe Element Number 362 (TEG-2P)

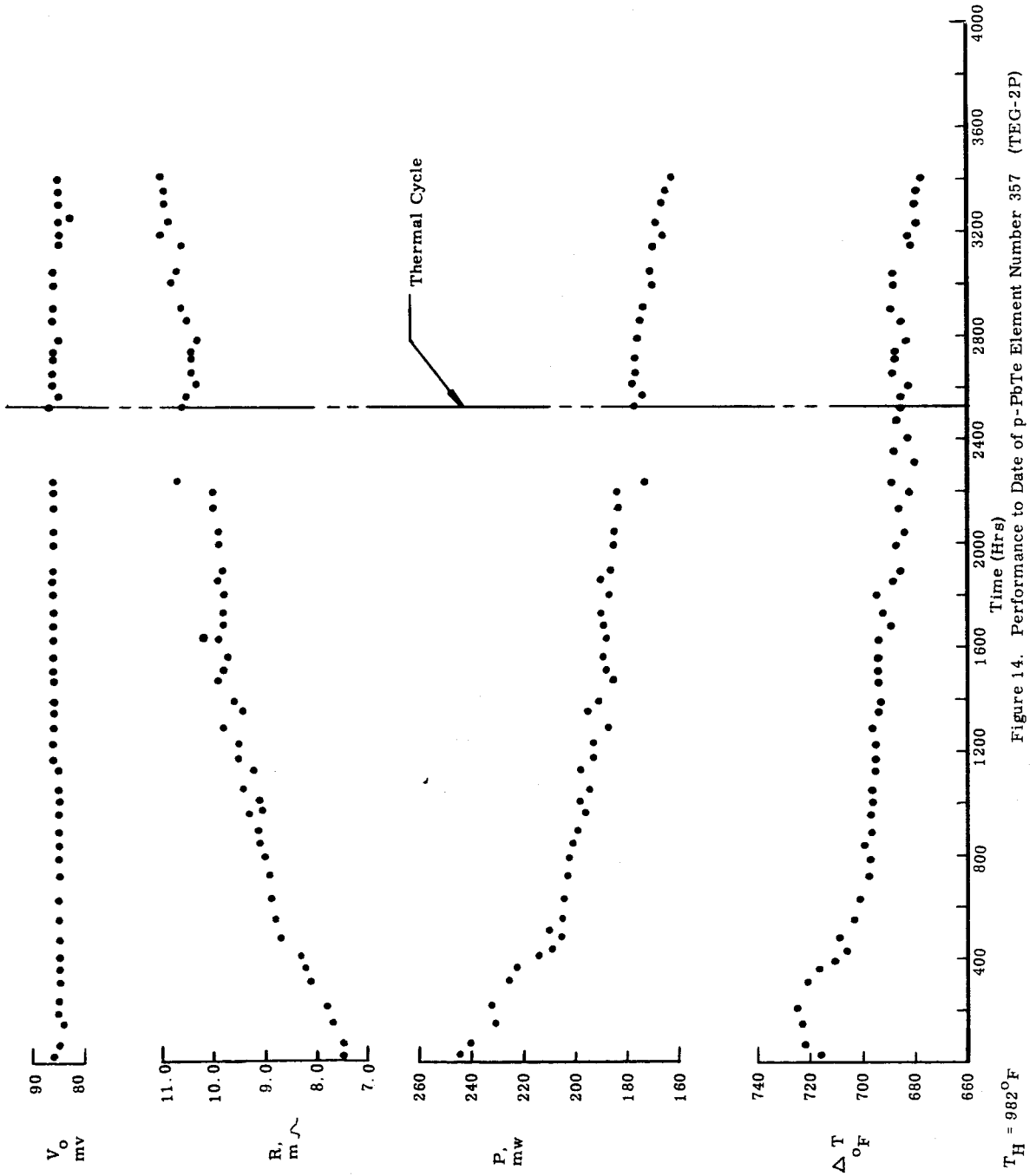


Figure 14. Performance to Date of p-PbTe Element Number 357 (TEG-2P)

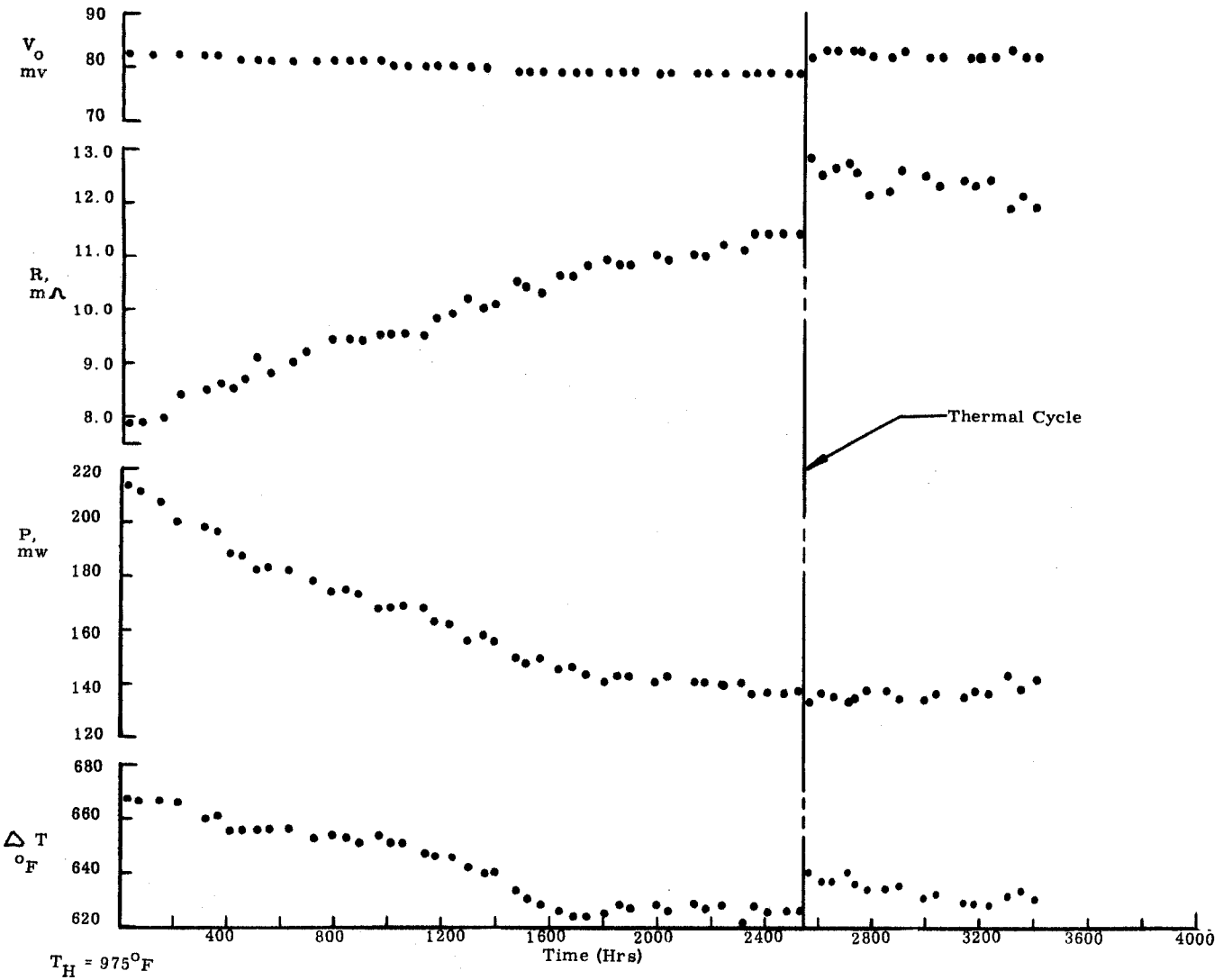


Figure 15. Performance to Date of p-PbTe Element Number 352 (TEG-2P)

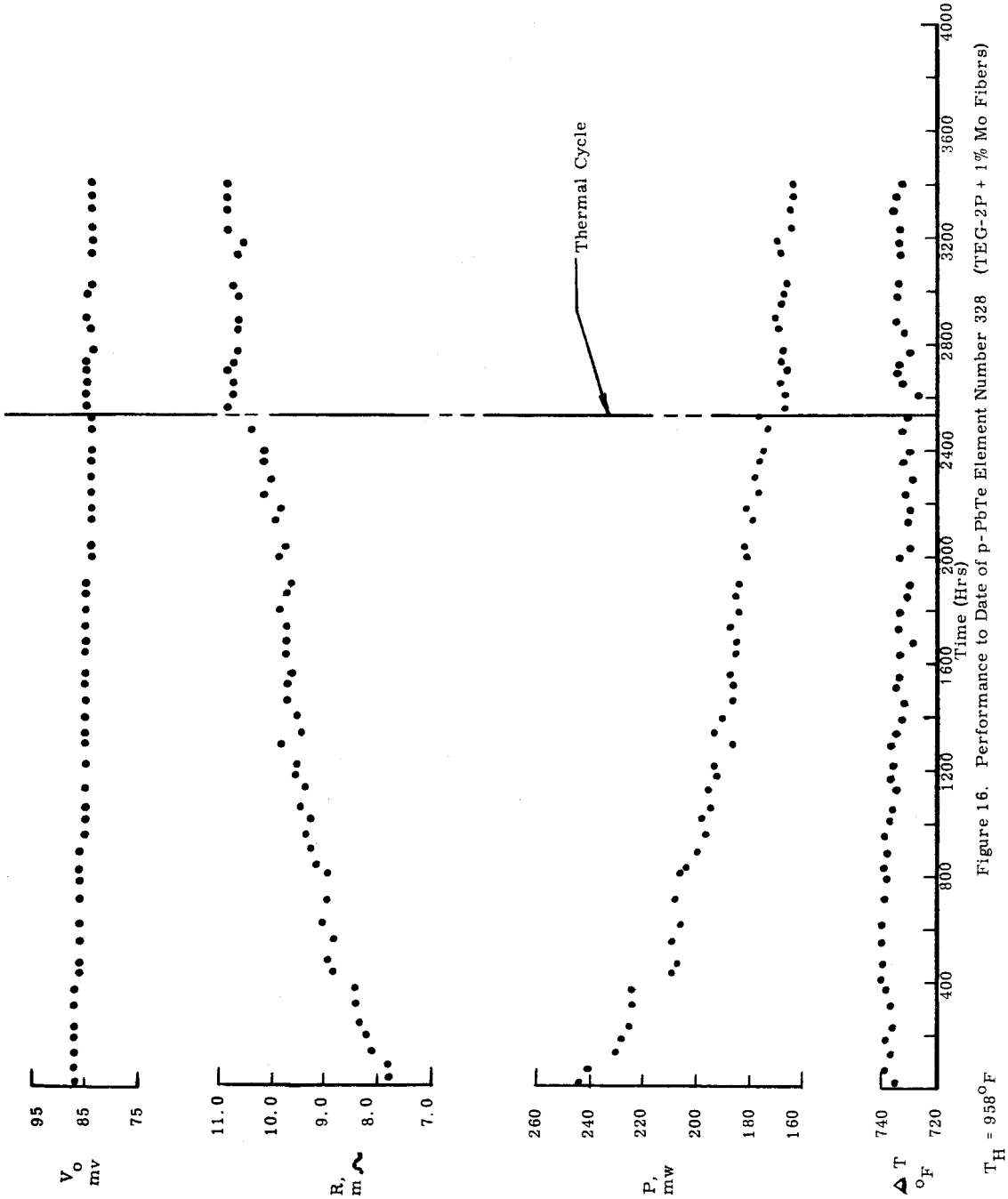


Figure 16. Performance to Date of p-PbTe Element Number 328 (TEG-2P + 1% Mo Fibers)

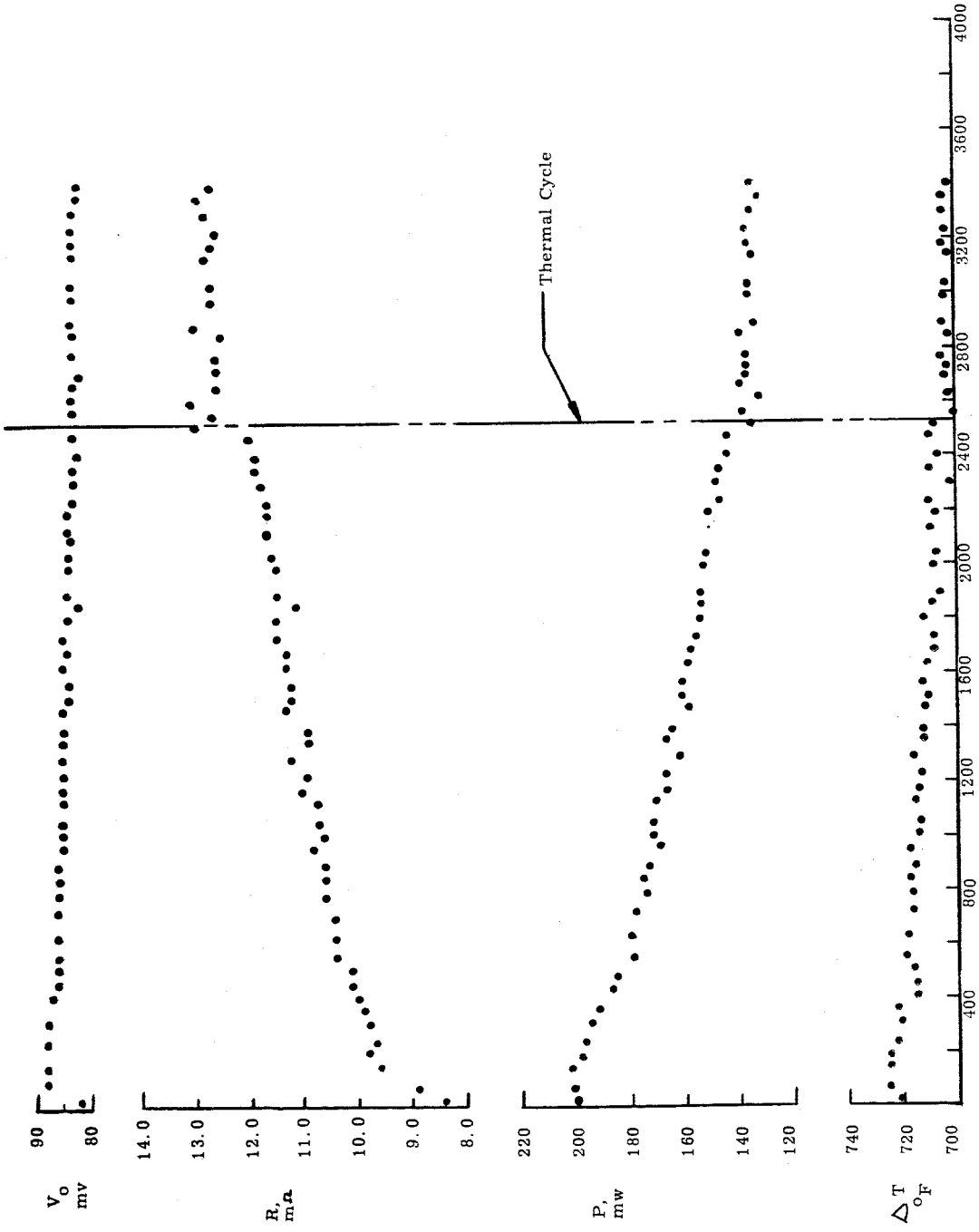


Figure 17. Performance to Date of p-PbTe Element Number 308 (TEG-2P + 1% Mo Fibers)

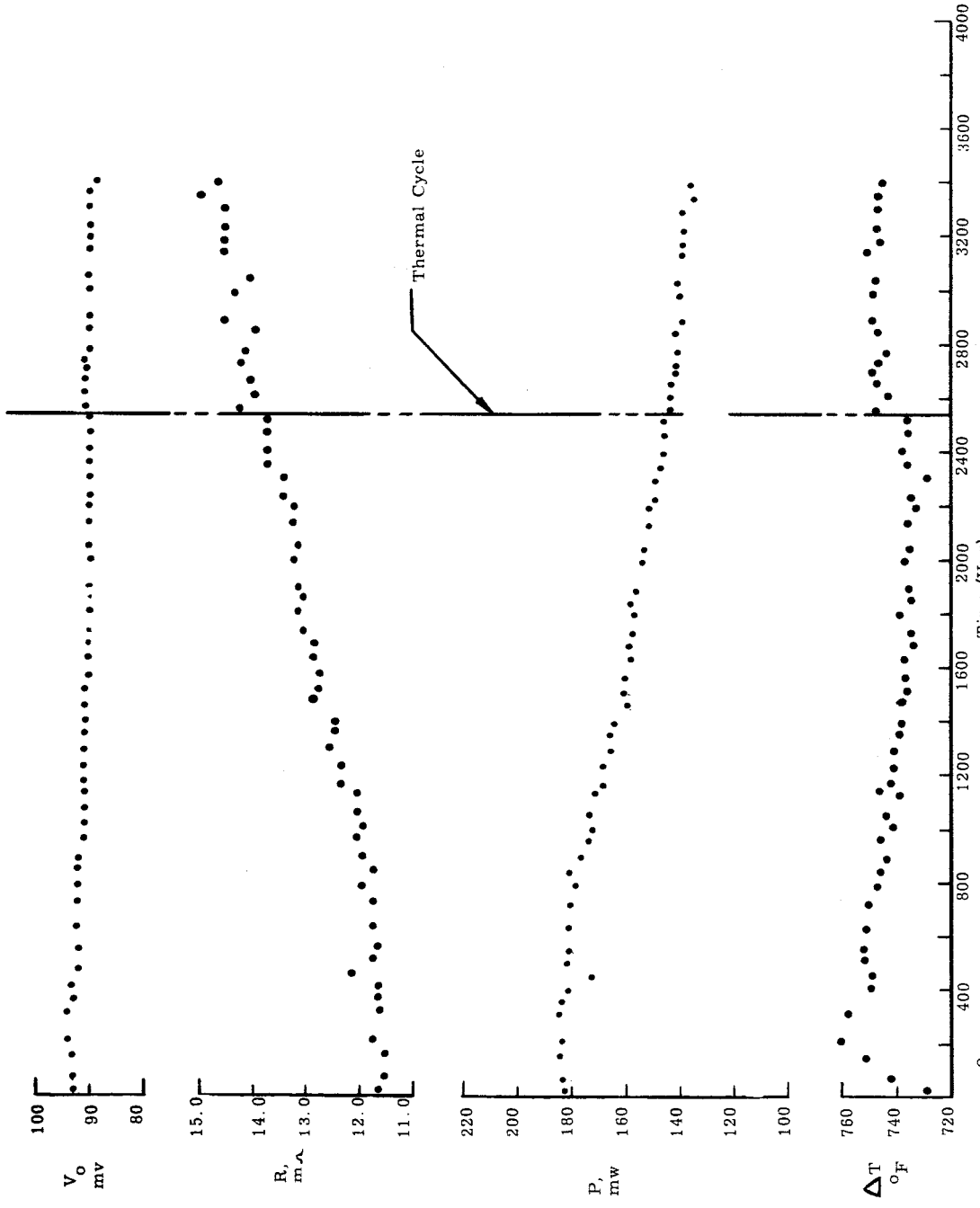


Figure 18. Performance to Date of p-PbTe Element Number 315 (TEG-2P + 1% Mo Fibers)

III. EFFECT OF ADDITIVES ON PROPERTIES p-PbTe

Early in this program it was demonstrated that p-PbTe is substantially weaker than the n-type material and that this inherent property frequently leads to cracking and breakage during bonding and subsequent handling. In order to treat this problem the possible strengthening effects on p-PbTe of several metal and oxide additives were studied during the previous phase. The results, reported in Reference 1, indicated that molybdenum and tungsten effectively strengthen p-PbTe and that Al_2O_3 in the form of sapphire fibers gave indications of similar performance.

Additional studies of these three additives were carried out as part of the current program. Three forms of molybenum, fine wire and two powders were included in this investigation. Two diameters of wire and two powders comprised the tungsten additives. Several forms of alumina had been tested previously and of these only sapphire fibers appeared promising so our study was limited to this material. The additives tested are described in detail in Table II. Two lots of p-PbTe powder, type TEG-2P purchased from 3M Company, were used in this study.

All test elements were produced in the form of hot pressed pellets 3/8 inch in diameter by approximately 3/4 inch high. The manufacturing procedure is similar to that used previously. The PbTe and additive powders were weighed out in a dry box. If the additive was tungsten or molybenum wire these were first degreased and cleaned and cut into lengths of approximately 1/8 inch. Other additives were used as received. The ingredients were than mixed and placed in a clean graphite die. Separate dies were used for each additive listed in Table II to prevent possible cross contamination of the hot pressed elements. New dies were first baked out at a temperature in excess of the hot pressing temperature to remove any volatiles that might be present. The ends of the die pins were lightly coated with Al_2O_3 to minimize sticking.

Hot pressing was carried out in an argon atmosphere at 1500°F. Pressure of 1.25 tsi was held for 5 minutes and the elements were cooled to room temperature under load. The appearance of samples containing molybdenum or tungsten was generally sound with no cracks and few, if any, chipped corners. Elements containing Al_2O_3 and control samples without additives displayed more frequent cracking and chipping. The addition of Al_2O_3, in fact, made hot pressing more difficult and two of the four thermoelements made with the sapphire fibers broke during removal from the die or shortly thereafter.

A. Effect of Additives on Thermoelectric Properties

Room temperature resistivity and low temperature Seebeck coefficient were measured on all elements processed during this task. The results are summarized by type of additive in Table III. Because of wide differences in resistivity of the two lots of TEG-2P lead telluride powder used in these samples data are reported separately for each lot of powder. The first row in this table lists the properties of elements containing no additives. Typical of our previous experience and that of other investigators, measured resistivity and Seebeck coefficient values were below those published by 3M for this material and below the values supplied as quality control release data.

TABLE II

Additives to p-PbTe Studied During this Phase

Additive	Form	Source
Molybdenum	-325 mesh powder, 99.9%	Consolidated Astronautics
Molybdenum	powder, mesh size not stated but appeared finer than the -325 mesh powder described above, 99.95%	United Mineral and Chemical
Molybdenum	0.001" diameter wire	Sylvania Electric Products
Tungsten	-325 mesh powder, 99.9%	Consolidated Astronautics
Tungsten	powder, mesh size not stated but appeared finer than the -325 mesh powder described above, 99.999%	United Mineral and Chemical
Tungsten	0.001" diameter wire	Sylvania Electric Products
Tungsten	0.0005" diameter wire	Sylvania Electric Products
Alumina	Sapphire fibers	Thermokinetic Fibers

TABLE III

Effect of Additives on Thermoelectric Properties of p-PbTe

Additive	Samples made from Lot 1047 TEG-2P Powder			Samples made from Lot 1089 TEG-2P Powder		
	No. of Samples	Av. Resistivity $\mu\Omega$in	Av. Seebeck % Dev. from Pub. 3M Value	No. of Samples	Av. Resistivity $\mu\Omega$in	Av. Seebeck, % Dev. from Pub. 3M Value
No additives	15	171	- 8.3	13	141	- 7.4[1]
1% Mo Powder 99.9%	2	190	-19.5	6	129	-17.5
4% Mo Powder 99.9%	2	189	- 3.5	0	---	---
1% Mo Powder 99.95%	0	---	---	3	144	-14.3
2% Mo Powder 99.95%	1	231	- 9.0	3	145	-18.0
1% Mo Wire	5	179	-17.0	6	157	- 9.0
2% Mo Wire	2	198	- 7.5	0	---	---
4% Mo Wire	3	181	-24.3	0	---	---
1% W Powder 99.9%	2	173	- 9.0	6	142	- 9.1
4% W Powder 99.9%	2	168	+ 5.0	0	---	---
1% W Powder 99.999%	3	158	- 9.5[2]	3	125	- 8.7
2% W Powder 99.999%	3	184	- 6.3	3	132	-14.3
1% W Wire[3]	3	175	-12.7	6	130	-10.8
2% W Wire[3]	2	196	-11.0	0	---	---
4% W Wire[3]	5	218	-19.0	0	---	---
1/2% Al_2O_3 Fibers	1	315	- 5.0	0	---	---
1% Al_2O_3 Fibers	1	238	- 1.0	0	---	---

(1) Two samples with unusually high Seebeck coefficient omitted
(2) One sample " " " " " "
(3) Results are combined for 0.0005" and 0.001" diameter W wire

From Table III it can be seen that molybdenum tends to increase the resistivity of p-PbTe. This effect was fairly small and was almost nonexistent in samples made with powder from Lot #1089. There was an indication of small negative effects on the Seebeck coefficient. Tungsten, with the exception of samples containing 2 and 4 percent wire additives, had no effect on the resistivity of p-PbTe. Neither of the tungsten powder additives affected the Seebeck coefficient but wire additions had a slight negative effect. Since the total surface area of the wire additions is smaller than that of the powder additions, any changes in thermoelectric properties would normally be expected to be greater in samples in which the additive was in the powder form. Since this has not been observed, it may be concluded that the effects on thermoelectric properties caused by wire additions stem from impurities in the wire or surface contaminants not removed during cleaning.

Only few samples containing sapphire fibers were fabricated and of these, two broke before any measurements could be made. The electrical resistivity of the other two were unacceptably high, hence Al_2O_3 is no longer considered to be a promising additive and no further samples were produced.

The first of a series of 1000 hour life tests of p-PbTe containing additives was placed in operation during this period. The six samples include p-PbTe containing 4 percent molybdenum powder, 4 percent molybdenum wire, 1 percent tungsten powder, 1 percent tungsten wire, 1 percent Al_2O_3 fibers and a control element without additives. The results of this test will be reported during the next quarter.

B. Effect of Additives on the Strength of p-PbTe

Several additional torsion tests were performed on p-PbTe thermoelectric elements containing molybdenum and tungsten additives. As in previous tests the elements were bonded to iron shoes each of which had a hex nut for gripping, machined into one end. A typical torsion test sample is shown in Figure 19.

Table IV reports the results of torsion tests performed at room temperature and Table V contains results of a series of tests carried out at 1000°F. At both temperatures the elements containing additives were stronger than p-PbTe without additives. Further, molybdenum is consistently more effective than tungsten in strengthening p-PbTe. These results are consistent with those reported earlier (Reference 1). However, the absolute value of the room temperature strengths measured recently appeared to be lower than those reported earlier. The lots of lead telluride powder used in these tests were checked and it was found that the samples reported in Reference 1 were made from powder identified by 3M Company as coming from Lots #1002 and 1047. Those elements whose properties are reported in Table IV were made from powder supplied as Lot #1089 except for the 4 percent molybdenum sample which used powder from Lot #1047. This sample was substantially stronger than the others in this test group and while it was at first felt that the high strength was due to the large quantity of molybdenum, it may well be that the inherently greater strength of material from Lot #1047 compared to Lot #1089 contributed at least part of the observed difference.

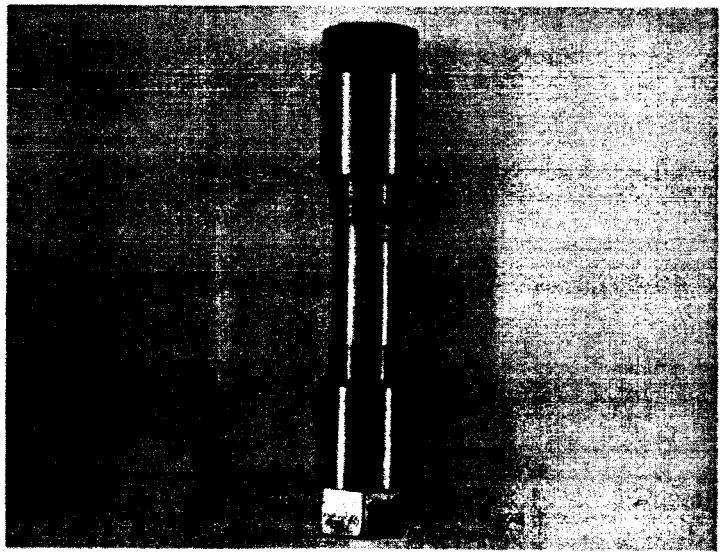


Figure 19. Torsion Test Specimen of PbTe Bonded to Iron Shoes

TABLE IV

Torsion Strength of p-PbTe Containing Additives (Room Temperature)

Additive	Torsion Strength, psi	Remarks
p-PbTe no additive	400	Separated at brazed interface
p-PbTe no additive	250	Broke within element
1% Mo Powder	700	Helical crack in element near braze
4% Mo Powder	1900	Helical fracture in element
1% Mo Wire	700	Helical fracture in element
1% Mo Wire	1000	Separated at braze interface
1% W Powder	550	Helical crack in element near braze
1% W Powder	600	Separated at braze interface
1% W Wire	500	Helical separation within element
1% W Wire	450	Helical separation within element

TABLE V

Torsion Strength of p-PbTe Containing Additives (1000°F)

Additive	Torsion Strength, psi	Remarks
p-PbTe no additive	850	Broke within element
4% Mo Wire	1800	Helical fracture
2% W Wire	950	Helical fracture
4% W Wire	1150	Helical fracture
4% W Wire	1100	Broke within element

During earlier work, samples of bonded p-PbTe were tested at 600° and 1000°F and it was observed that the strength was independent of test temperature (Reference 2). Comparison of the results reported in Tables IV and V indicate, at first glance, that the samples tested at 1000°F during this program are considerably stronger than those tested at room temperature. However, the elevated temperature test samples were all fabricated from Lot #1047 powder. When the 1000°F results are compared with those reported at room temperature in Reference 1, the results are quite comparable except for the single element containing no additive which appears to be somewhat stronger than expected. Further tests will be required to resolve this anomalous lot to lot variation in properties.

The efficiency of molybdenum and tungsten in strengthening p-PbTe has been satisfactorily demonstrated despite the observed variations in data.

IV. BONDING OF LEAD TELLURIDE TO STAINLESS STEEL SHOES

The stress due to differences in the rate of contraction during cooldown between the shoe and thermoelement is believed to be a major cause of cracking in bonded lead telluride thermoelectric elements. Iron, for example expands or contracts at little more than one half the rate of lead telluride. Since austenitic stainless steels, i.e. 300 series stainless, have thermal expansion coefficients closely matching that of lead telluride, a preliminary study of bonding to stainless shoes appeared to be a logical step.

Five experimental bonding runs have now been performed. In each three p-PbTe elements, hot pressed from the same lot of powder, were prepared for bonding by the procedures described in Reference 1. One was mated to iron hot and cold shoes and the other two to identical shoes machined from Type 304 stainless steel. In three of the five runs, the bonding process was that described in Reference 1 and included a final cooldown at the rate of 50°F per hour. In the other two bonding runs the rate of cooling was not controlled. Instead the inert atmosphere chamber in which bonding was carried out was removed from the furnace immediately after the five minute hold time at 1500°F was completed. Under these conditions, the temperature declined initially at about 30°F per minute and cooled to below 400°F within one hour.

Visual observation of the slow cooled specimens showed that the iron shoes were bright and clean, typical of those previously bonded in this system. The stainless steel shoes were somewhat tarnished, having a dark oxide, presumably Cr_2O_3 on the surface. Measurements of thermoelectric properties before and after bonding showed no changes. Bond resistances were similar in elements bonded to iron and stainless steel, being less than 100 micro-ohms in almost all cases.

The rapid cooldown attempted on two runs was an unsatisfactory procedure. The appearance of the stainless steel shoes was better since they had been exposed to high temperature for a considerably shorter period of time. However, at least one bond on each element had very high resistance (several hundred micro-ohms) indicating that the thermal shock had caused cracking.

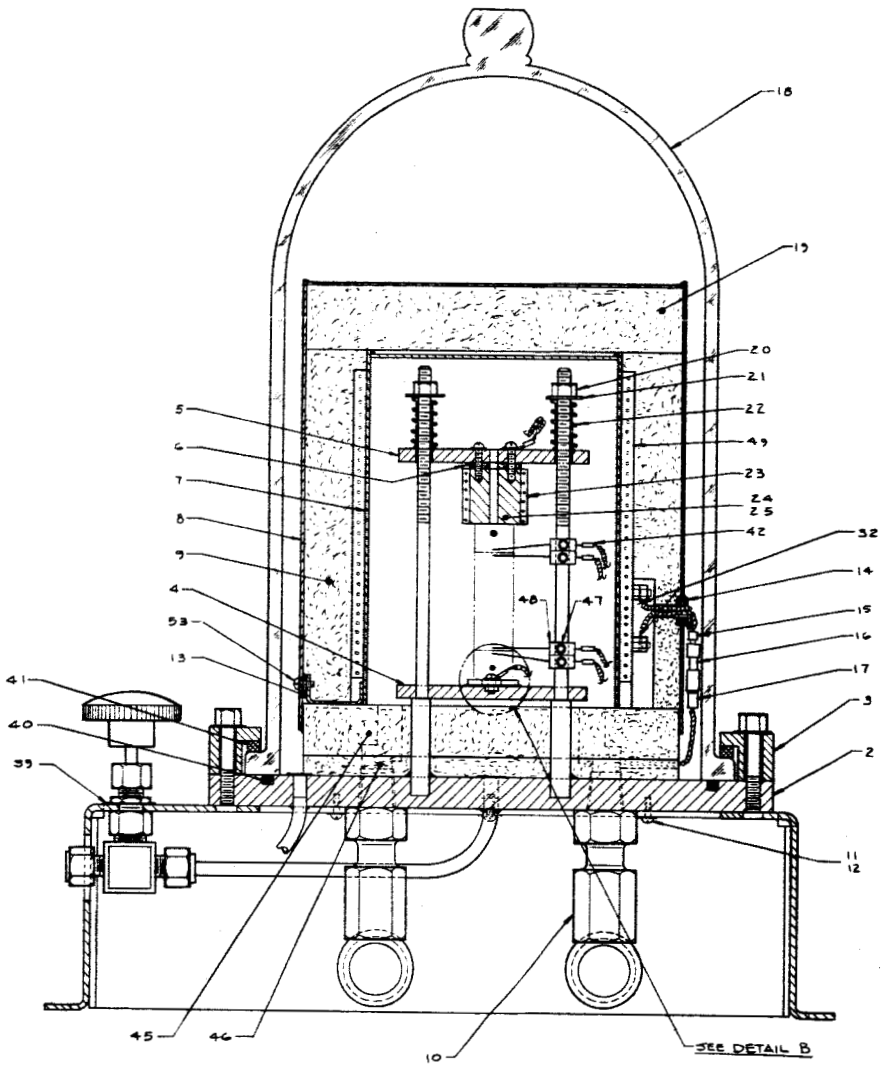
Several runs at intermediate rates of cooling are scheduled for the next quarter. Life tests and torsion strength measurements will also be made.

V. DESIGN OF EQUIPMENT

Design of a device for the simultaneous measurement of Seebeck coefficient and electrical resistivity of thermoelectric elements has been completed. The device, which is shown in Figure 20, consists of a bell jar within which an inert atmosphere or vacuum can be maintained, a small furnace, a heater at the top end of the specimen to establish a ΔT, and probes and related instrumentation to make measurements of selected voltage outputs and resistances. With this equipment measurements may be made of Seebeck coefficient, thermoelectric material resistivity and bond resistance to temperatures of 1000°F or higher.

Depending on the instrumentation selected, the output of this equipment can be read manually, recorded on strip charts for later manual calculation of properties, or recorded on punch cards or punched tape for computer processing of data Figures 21 and 22 show the control panel and wiring schematic for the system in which the data are recorded on charts for manual processing.

Preliminary design of a versatile couple and module tester is under way with completion scheduled for the next quarter.



SECTION THRU TESTER

	AR	ADHESIVE CEM		SILASTIC RTV732
	AR	ADHESIVE CEM		SAUEREISEN 32 AND
	3	#6-32 x 3/8 LG (SST)	53	SCREW, PAN HD. TAPPING
	1	"ARGON"	52	DYMO-MARKER & TAPE
	1	"VACUUM"	51	DYMO-MARKER & TAPE
	4	1877	50	GROMMET (ATLANTIC 1 RW.)
	1	5" I.D. x 6" LG (ASS'Y)	49	BAND HTR (HOT WATT)
	AR	494-0501	48	VOLTAGE PROBE ASS'Y
	AR	#8-40 x 1/4 LG	47	CAP SCREW, SOCKET HD. (SST)
	1	453-0001	46	BOTTOM INSULATOR
	1	452-0001	45	INNER INSULATOR
	2	.002" DIA x 2" LG	44	THERMOCOUPLE - CHROMEL-ALUMEL
	AR	70.0018	43	INSULATING BEADS (T-EX-500)
	AR	18 G	42	SPLICE
	1	447	41	SQ. CUT RING (PACKER)
	1	5-446-5451-7	40	O-RING (PARKER)
	2	.632 I.D. x 1.057 OD	39	WASHER, LOCK (INTERNAL)
	1	491-0001	38	ELECTRICAL INSULATOR
	1	490-0001	37	BUTTON CUP
	1	489-0001	36	ADJUSTMENT BUTTON
	1	#6-32	35	NUT, HEX. (SST)
	1	#6-32 x 5/8 LG	34	SCREW, 2D. HD. (SST)
	1	487-0001	33	COLD ELECTRODE
	4	.88 I.D. 18 G	32	TERMINAL, RING CRIMP
	3	.375 OD x .147 ID	31	WASHER, FLAT (SST)
	2	#6-32 x 3/4 LG	30	SCREW, 2D. HD. (SST)
	6	.688 O.D. x .266 ID	29	WASHER, FLAT (SST)
	6	#4-20 x 1 1/2 LG	28	CAP SCREW, HEX (SST)
	1	B-46 (VSPSI)	27	VALVE, CHECK (NUPRO)
	2	3T54	26	VALVE (WHITEY)
	1	486-0002	25	HOT ELECTRODE (SHOE)
	1	486-0001	24	HOT ELECTRODE (ELEMENT)
	1	1" I.D. x 1" LG (2 WATT)	23	BAND HTR. (HOT WATT)
	2	NC-055B-5	22	SPRING (INCONEL-X) (LEE CO.)
	2	.500 O.D. x .23 I.D.	21	WASHER, FLAT (SST)
	2	#12-24	20	NUT, HEX. (SST)
	1	485-0001	19	UPPER INSULATOR
	1	32460-KG-33	18	KIMAX BRAND 6 3/4 O.D.
	2	3-G1	17	FEMALE CONN. (SURE-LOK)
	2	3-G1 INSULATOR	16	INSULATOR (SURE-LOK)
	2	3-71	15	MALE CONN. (SURE-LOK)
	1	2903	14	GROMMET (ATLANTIC 1 RW.)
	3	484-0001	13	INSULATOR
	6	.438 O.D. x .200 I.D.	12	WASHER, FLAT (SST)
	6	#10-24 x 1/2 (SST)	11	SCREW, ROUND HD.
	2	MHM-040-A-16-T	10	CONNECTOR (CONAX CO.)
	1	483-0001	9	INSULATING SLEEVE
	1	482-0501	8	OUTER CAN ASS'Y
	1	481-0501	7	INNER CAN ASS'Y
	1	480-0001	6	SPACER
	1	479-0501	5	UPPER PLATFORM ASS'Y
	1	478-0001	4	BOTTOM PLATFORM
	1	477-0001	3	BELL JAR TIE DOWN RING
	1	476-0501	2	BASE ASS'Y
	1	475-0001	1	TESTER, STAND
QTY. UNIT'S REQ'D	QTY. UNIT'S REQ'D	PART NUMBER	ITEM	DESCRIPTION

LIST OF MATERIAL

UNLESS OTHERWISE SPECIFIED

THERMOELECTRIC TEST FIXTURE

472		
T/E TESTER		
~	~	J 474

Figure 20 Proposed Resistivity and Seebeck Coefficient Test Device

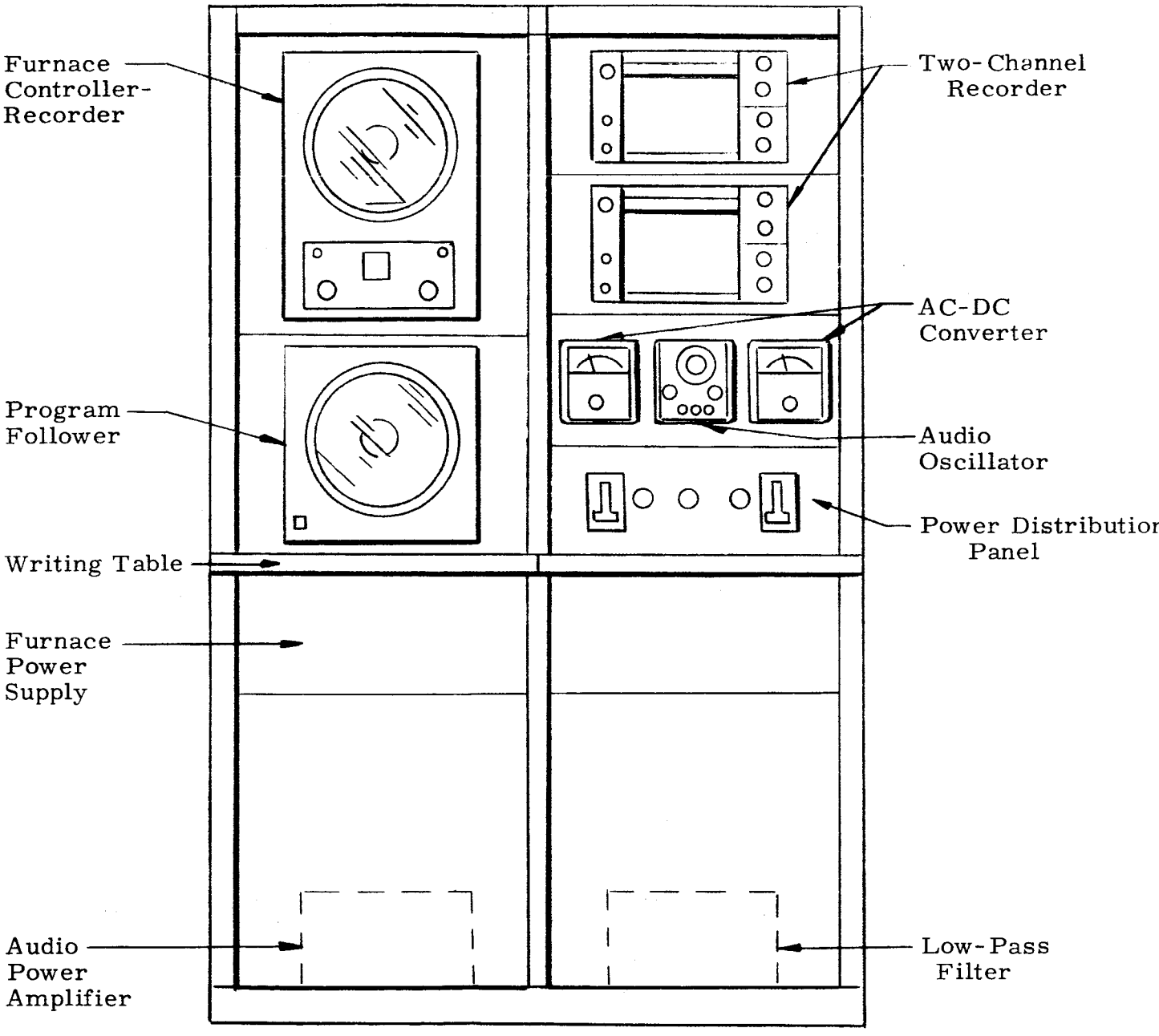


Figure 21 Control Console Schematic for Continuous Gross Resistance and Seebeck Monitor

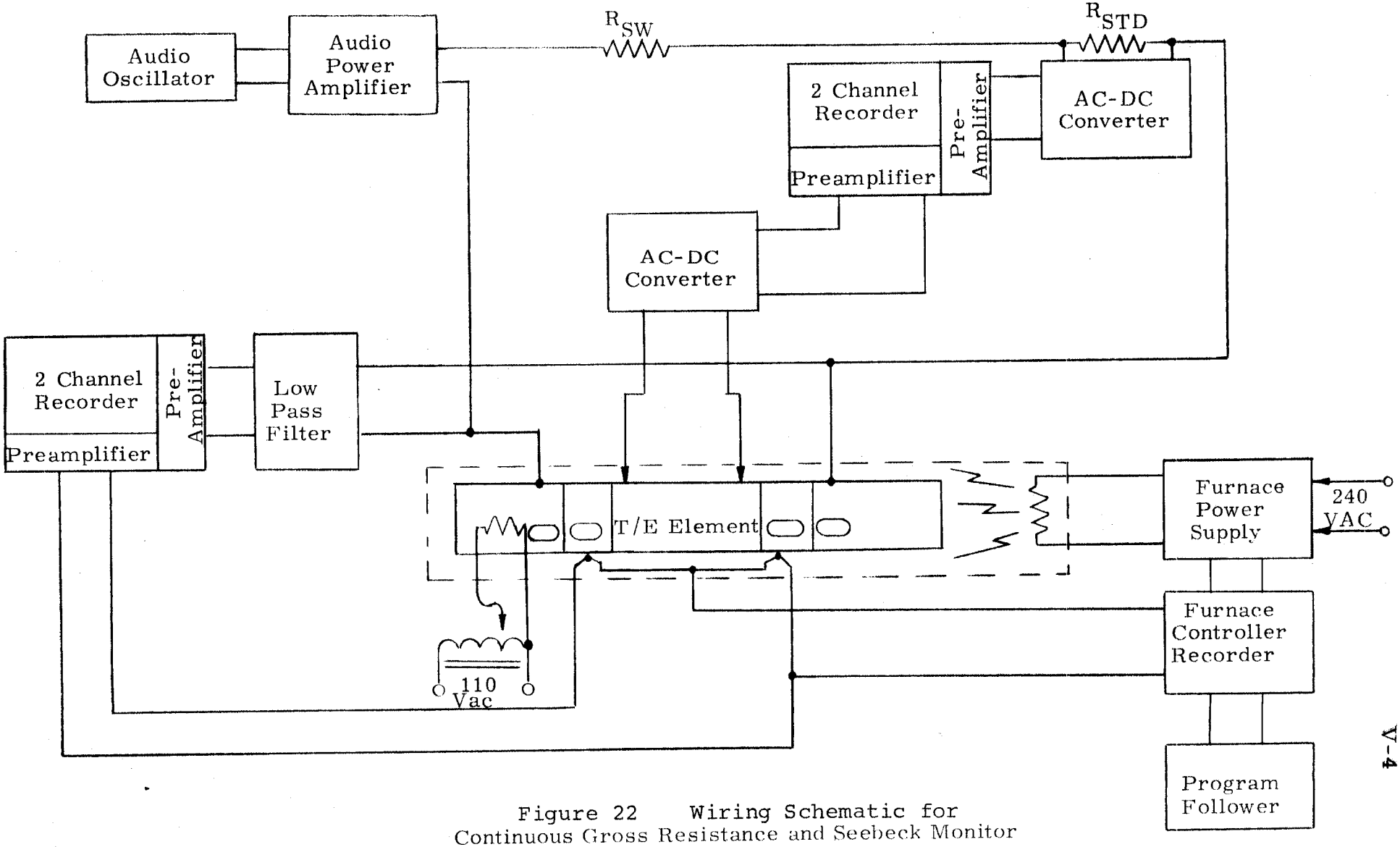


Figure 22 Wiring Schematic for
Continuous Gross Resistance and Seebeck Monitor

VI. REFERENCES

1. Abraham L. Eiss, Thermoelectric Bonding Study, Phase II, Summary Report, Report No. HIT-205 prepared under Contract NAS5-3973 by Hittman Associates, Inc. (April 1966).

2. Abraham L. Eiss, Thermoelectric Bonding Study, NASA-CR-369 (January 1966).